Titan Bumblebee : A 1kg Lander-Launched UAV Concept

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Bumblebee (*bombus*) is a subarctic insect, evolved to exploit periglacial terrain. Note the unaerodynamic appearance with insulating fur.
Bees must have warm flight muscles to fly - warm them before takeoff; do not drain a flower of nectar but only remain as long as muscles stay warm (see B. Heinrich's book 'Bumblebee Economics')

ADVANCED EXPLORATION VEHICLES TEND NOT TO FLY AS STANDALONE PLANETARY MISSIONS

Why -

Risks not well understood. Risk aversion argues to fly what is known
Science opportunities not well understood, so science pull is not strong (remedy by seed science funds?)

DS-2 Mars Microprobes - piggyback on Mars Polar Lander

VEGA Balloons - piggyback on Halley Flyby/Venus Lander

Sojourner Rover - piggyback on Pathfinder lander

PLUTO Mole - piggyback on Beagle Lander

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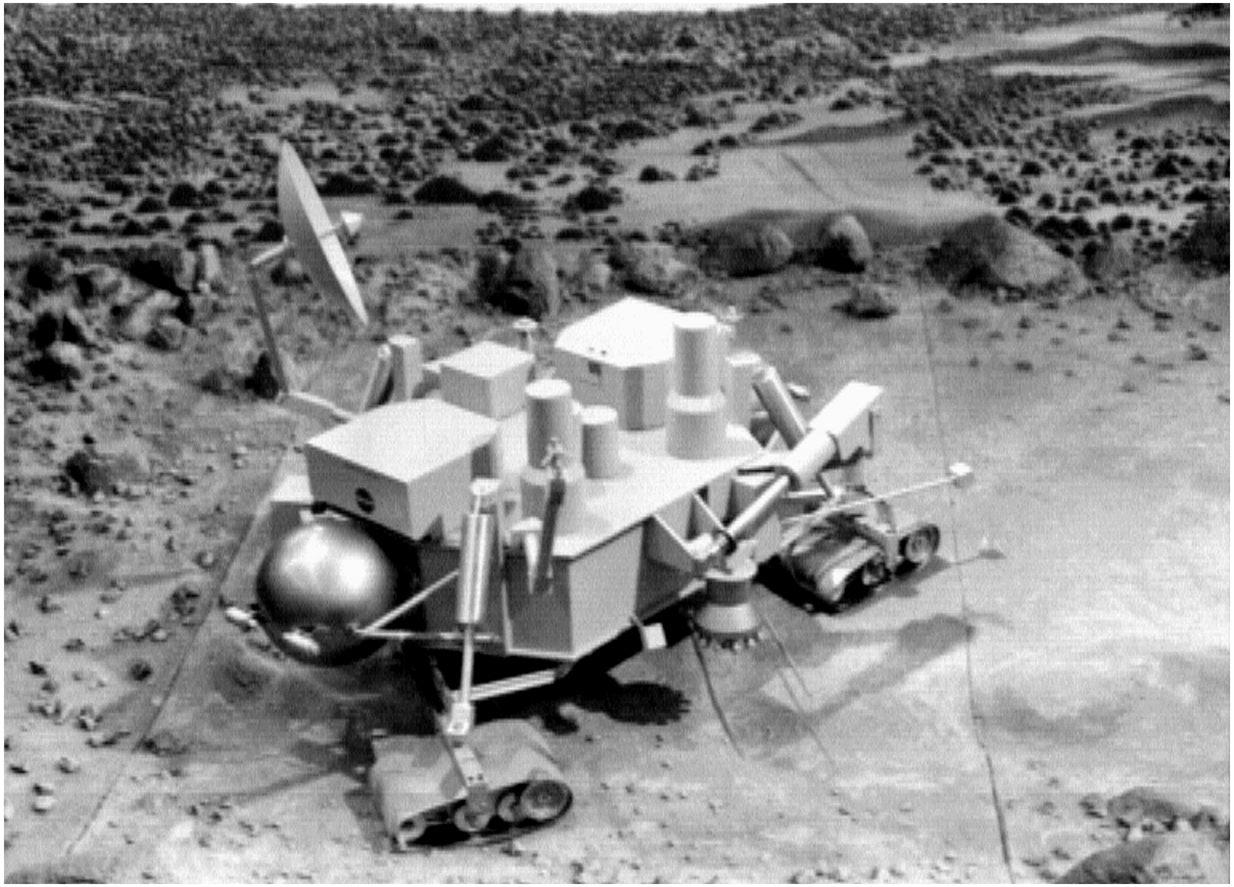


Who cares why. It is an empirical fact. Large, capable Mars science rover ('Viking 3') looked good in 1976, but it took MFE/Sojourner and 2xMER to get there

To live within this reality, balloons/moles/airplanes etc. must be only a subsidiary element. This means small.   In practical terms this also means non-nuclear.

Explore the minimum useful Titan airplane.

Start with 1kg (we will soon see smaller doesn't make much sense)

3 Convergent Factors :

Primary batteries (e.g. $LiSOCl_2$, per Huygens, Galileo) have specific energy of ~400 W-hr/kg. If we allocate half of our 1kg to batteries, we have ~200 W-hr (720kJ) This means 200W for 1 hour, or 50W for 4 hours, 10W for 20 hours.

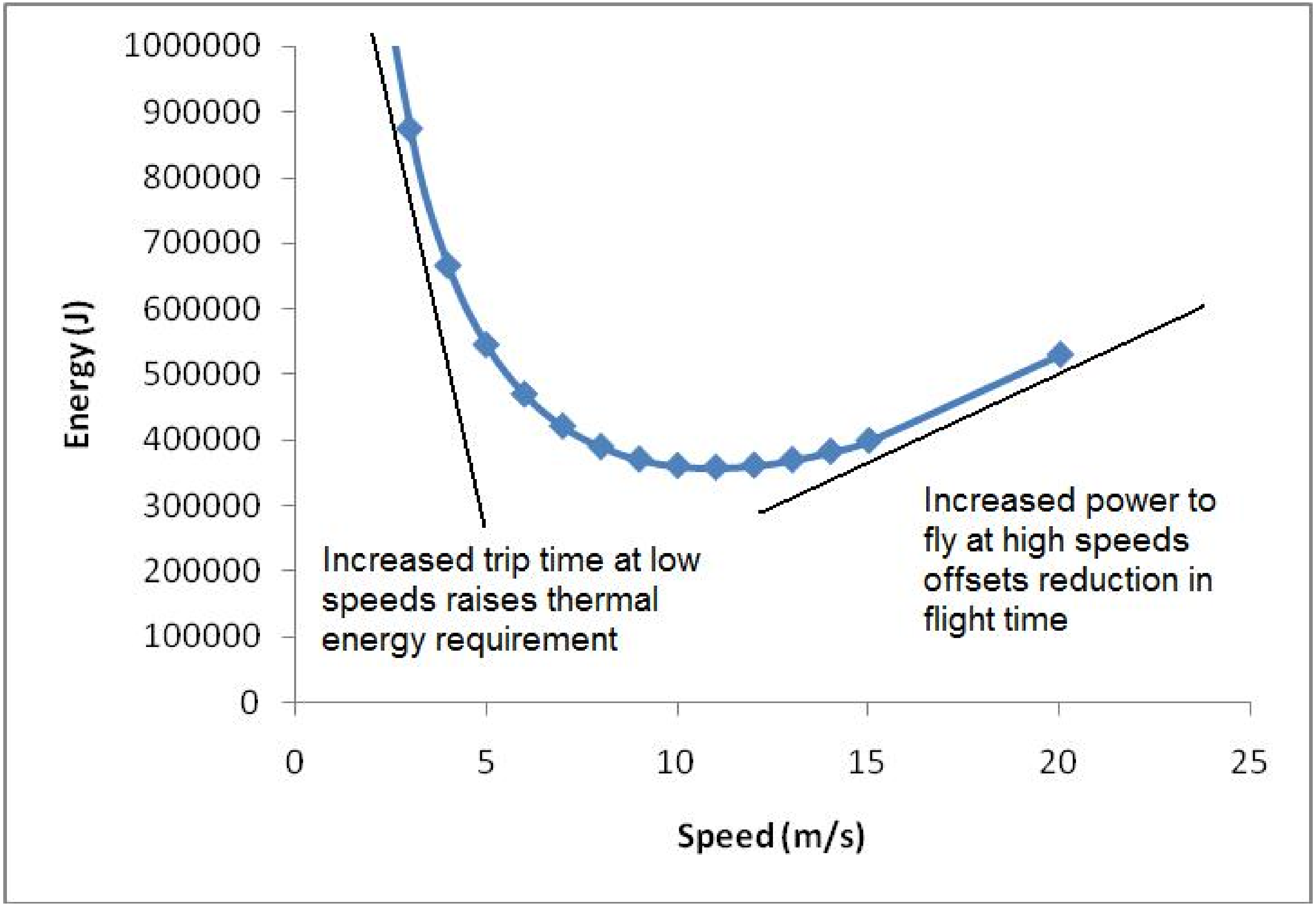
But vehicle must stay warm. 1kg equipment pod with density of ~1000 kg/m^3 has an area of 400cm^2. If we have a 0.5cm thick layer of foam insulation (Basotect, as on Huygens $k=0.02\ Wm^{-1}K^{-1}$) then with ΔT~200K required in 94K environment, we lose ~30W.

If near-surface winds are ~0.5-1 m/s, we need to fly at several m/s to penetrate. Empirical scaling relationships suggest flight power $P \sim 10.9\ m^{0.8}V^{0.9}(g/g_e)$.
For 1kg at 10m/s in Titan gravity ($g/g_e=1/7$) this means ~15W.

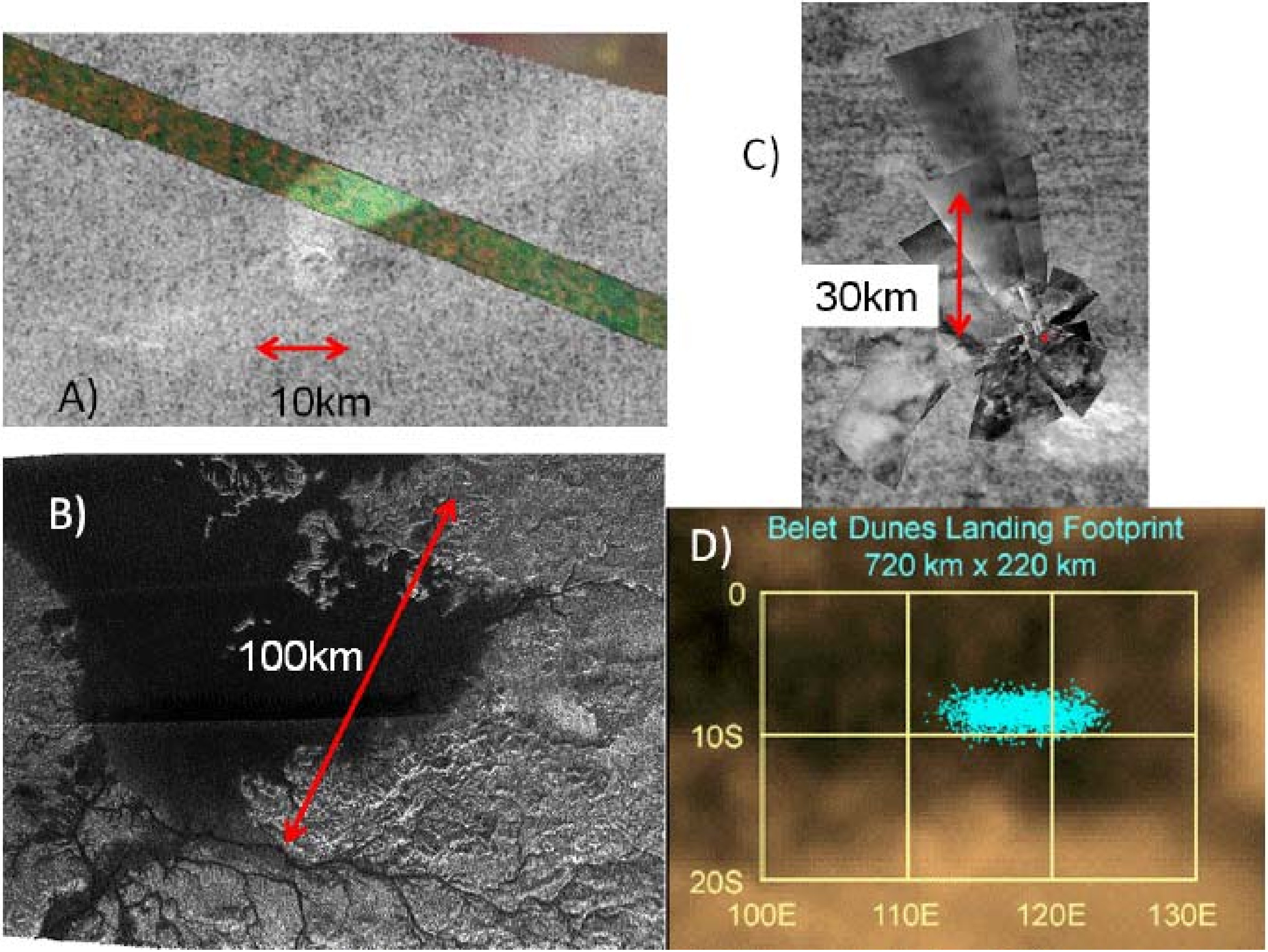
So, 4-6 hour flight seems possible.

Heat rejection from motor is usual problem for terrestrial vehicles. An exception is a recent autonomous UAV project (British Antarctic Survey/TU Braunschweig) used to study air:surface boundary layer heat fluxes in the Weddell Sea, Antarctica. 45km flights ~ 40 minutes. For small UAVs in cold environment, insulation is required.

In fact insulation/convective heat transfer pathways must be tuned (duct tape.) When adjusted for warm steady-state flight, only 10 mins of static operation on ground will cause batteries to overheat! (Phil Anderson, BAS, Personal communication, 2008)



Energy requirement to fly 100km



A)
10km
B)
100km
C)
30km
D)
Belet Dunes Landing Footprint
720 km x 220 km
0
10S
20S
100E
110E
120E
130E

Need to communicate via lander (and use lander as beacon for navigation?)

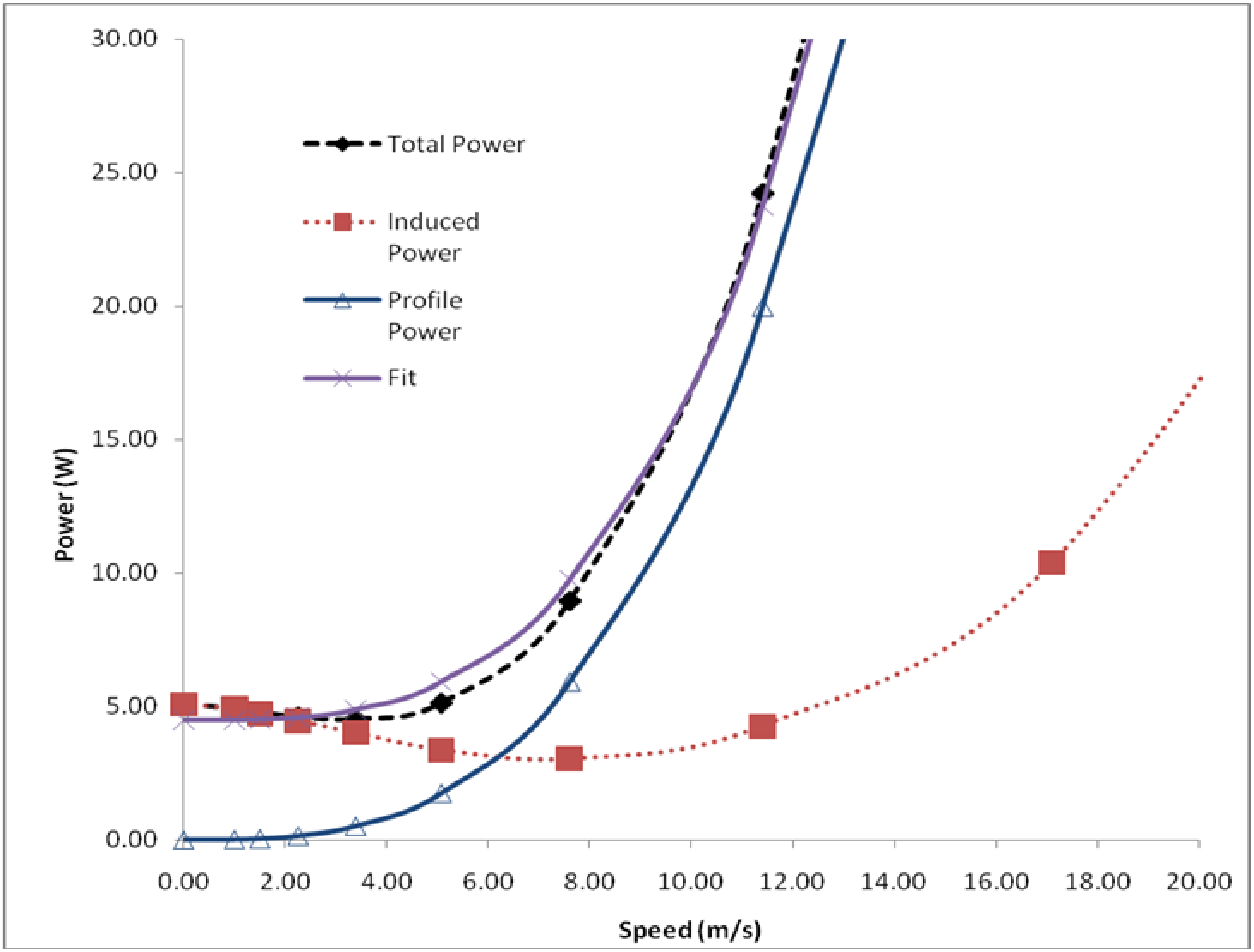
Horizon distance at Titan for altitudes of 0.1, 1, and 2km altitude is 22, 71 and 101 km away. So we can fly at low altitudes for some tens of km, perhaps 100km away and remain in line-of-sight (ignores multipath, terrain blocking, refraction)

Lander delivery ellipse is ~70x240km 1-sigma, so to fly 100km would be useful (gives good probability of reaching given point in the ellipse)

At 10 m/s, cover 100km in 3 hours.

RF power for 'video' rate telemetry is ~few to ten W (DC).

Flying at 1km, see a swath ~1km wide. With 1m/pix, then 100x1 km long swath, or 10^8 1x1m pixels. In other words, some GB of potentially useful data. Comparable with mosaic from a panoramic camera. (Not worth acquiring more data than this unless have clever data selection or a very good downlink capability..?)



Example power curve for pure rotorcraft (no wings) computed with JAVAPROP (fit is ~V^3 + constant) . Above ~7 m/s profile power dominates. Vertical takeoff needs only comparable power with cruise.

System	Power (We)	Internal (%)	Dissipation (Wth)
Controls	2	100	2
Payload	2	100	2
Propulsion	10	10	1
Telemetry	6	60	3.6
Heaters	10	100	10
Total Electrical	30	10	3
Total Thermal			21.6

Table 1. Example power budget. Electrical power dissipated in the control system, payload and heaters translates directly into supplied heat. A fraction of the telemetry power and motor power is converted into heat in the transmitter and motor respectively, as is a small fraction of the total electrical power which is dissipated by the battery's internal resistance and power conditioning electronics.

Tradeoffs to explore

Larger UAV - more science capability/range/endurance: probable thermal performance improvement via mass/area scaling. But more cost, volume.

Thicker insulation - lowers thermal energy requirement. But increases aerodynamic drag. Insulation performance ultimately compromised by instrument/propulsion/electrical penetrations and feedthroughs

Slender or stubby. Slender has lower drag but higher heat loss area. Blended wing-body? Wings ? Or just rotor.

Flight speed. Altitude (High is safer, easier comms. more area imaged, but lower resolution. Longer path for CH_4 absorption; gas and haze scattering. Profiles desirable for boundary layer meteorology)

Rotor diameter, speed. (Stall for vertical takeoff; tip speed Mach…)

Motor inside insulation or outside ? (~10% of flight power dissipated inside adds to thermal budget, but have shaft feedthrough..)

Guidance

Must fly in daytime (illumination for imaging, plus sun position as a heading reference - remember no GPS, no magnetic field)

Pressure altimeter. Pitot airspeed.

More robust to incorporate additional heading/position reference - use lander as a beacon. UAV antenna systems for emitter location are in use.

(Some less robust but conceivable possibilities - Groundspeed via optical odometry? Inertial guidance? Radar ? Sonar?)

Payload

Nominally Side-looking camera plus meteorology

(heavier variant could consider spectrometer, UV-fluorescence etc. for astrobiology survey of cryolava flows etc.)

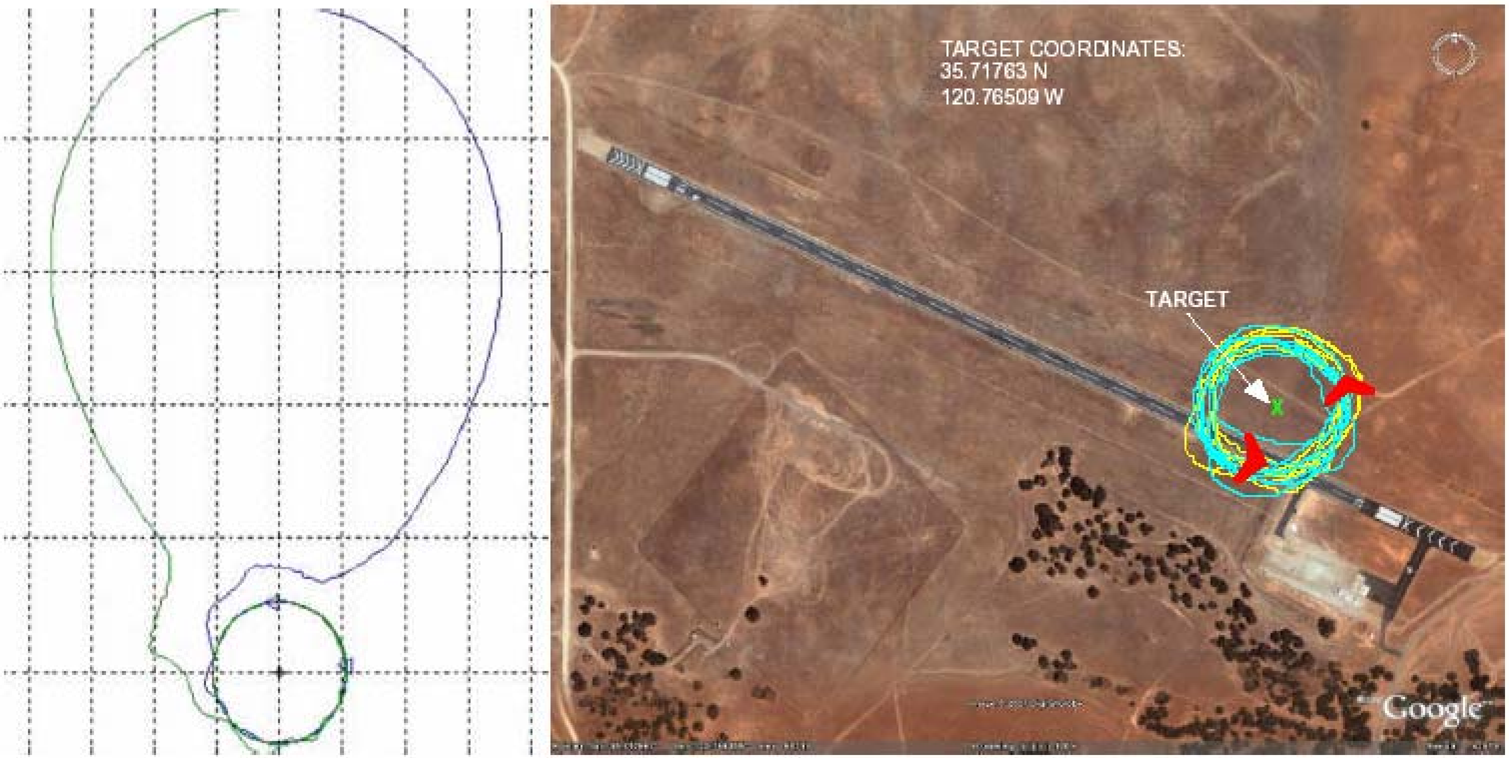


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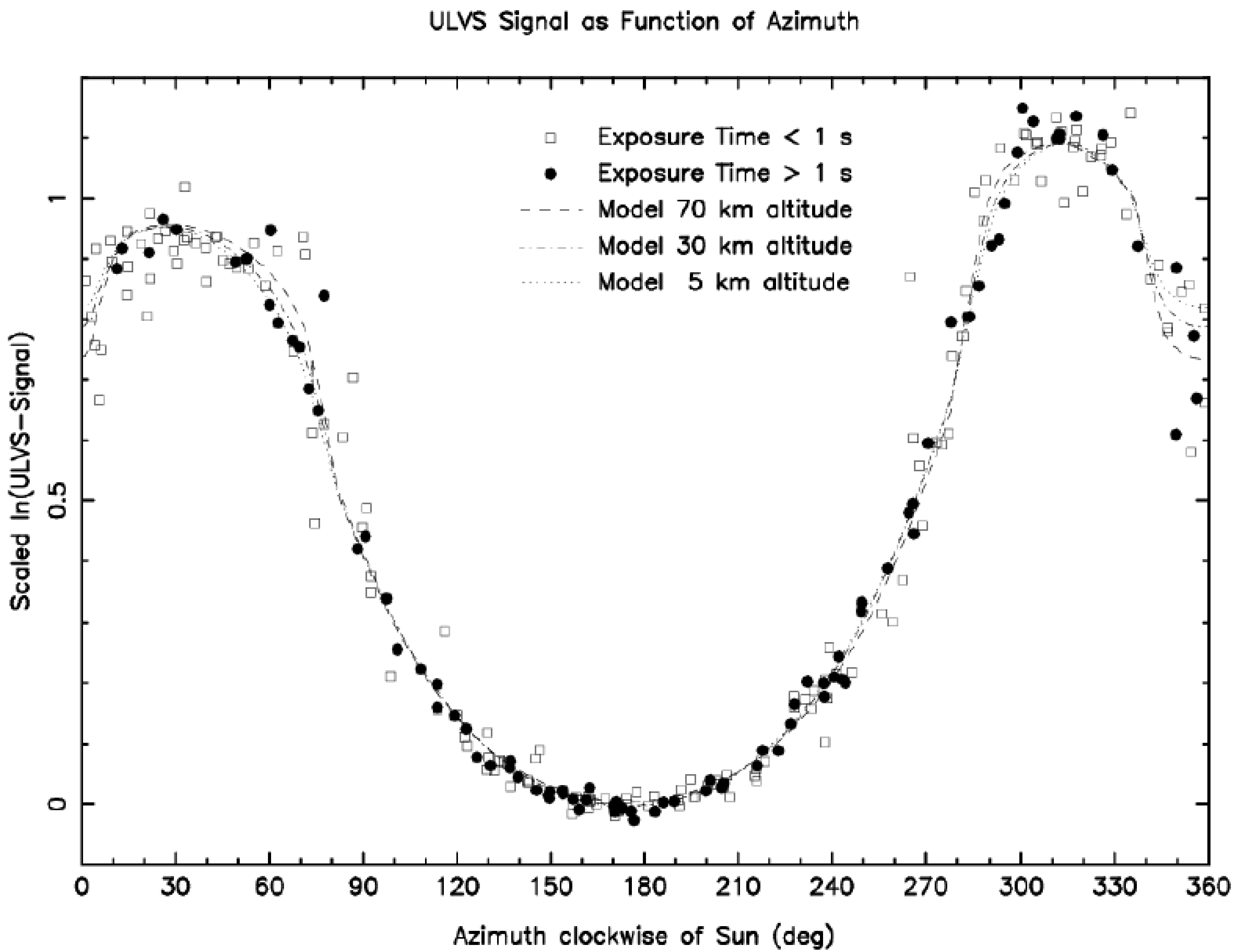
Figure 7. Simulation on the left, and the corresponding flight on the right, show orbit of the target by two UAVs (in this application the two UAVs space themselves automatically around the emitter to minimize its location uncertainty). From Bamberger et al. (2008)



ULVS Signal as Function of Azimuth
Exposure Time < 1 s
Exposure Time > 1 s
Model 70 km altitude
Model 30 km altitude
Model 5 km altitude
Scaled ln(ULVS-Signal)
0
0.5
1
0
30
60
90
120
150
180
210
240
270
300
330
360
Azimuth clockwise of Sun (deg)

Commercial/Military small-scale Ducted Fan UAVs are proliferating.

Ducted Fan obviates rotor hazard, introduces some improvements in controllability.

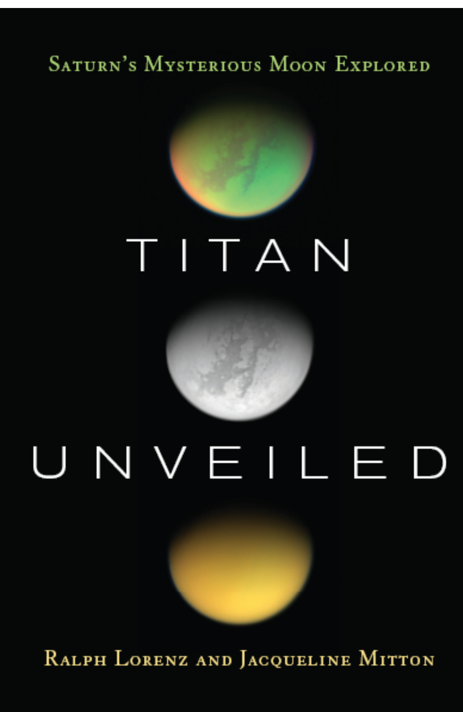
Lander-Launched Micro-UAV for Titan Science

USMC has hundreds of Back-packable Dragon Eye UAVs. Mass 2.7 kg. Endurance ~60 minutes on battery. Range ~ 10km. Video to backpack/ laptop control station. Cruising speed 35 km/h.

~1kg Titan UAV could fly for several hours (vertical launch off lander) – augments/replaces descent imager landing site context (stereo, λ, lander in scene), plus boundary-layer meteorology profiling.

Can have much smaller wing area in Titan low gravity, thick atmosphere (or could fly 5x slower)

Possible implementation as competed student experiment ?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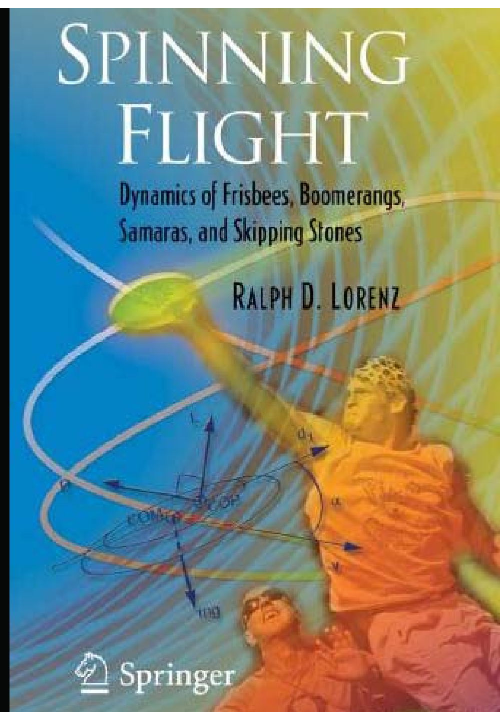
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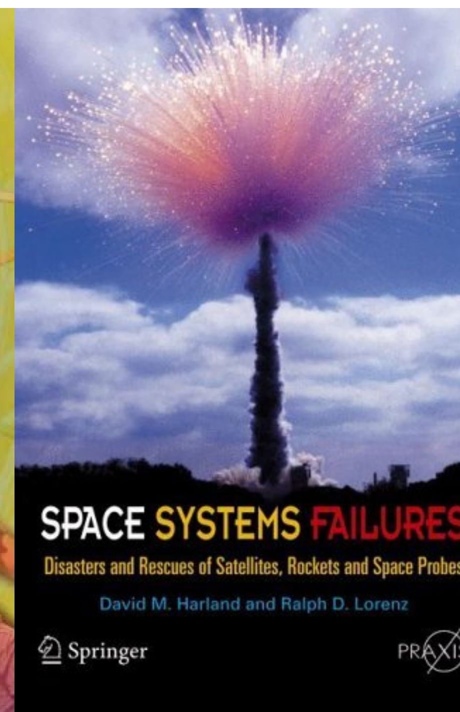
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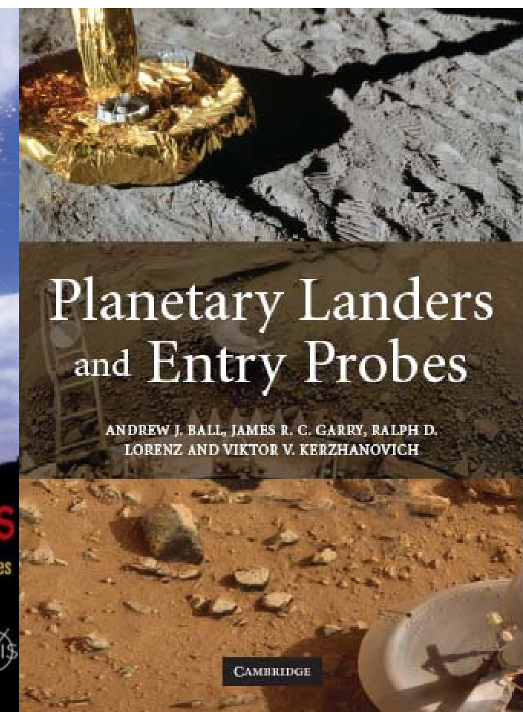
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